Mother and Child Health Care System Based on the Analysis of Population Databases and Clinical and Immunological Characteristics of an Individual Patient*

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Abstract. The system of maternal and child health care is presented. The peculiarity of this system is that it combines control algorithms developed for population and individual health. The general principle of the system functioning and separate algorithms are presented. The article deals with the algorithms for forecasting the viability of a newborn, the development of intrauterine infection, including the premature rupture of fetal membranes, the development of a number of gynecological diseases (such as adenomyosis), the effectiveness of the IVF program. The most developed models are based on predictive models. The models were built using different methods: logistic regression, random forest, neural networks. The application of algorithms at the population level allows estimating the need for specialized obstetric care and coordinating the work of intensive care units. The application of algorithms at the individual level will help to determine the best tactics of patient management and minimize the risk to the health and life of a newborn and mother.

Keywords: Maternal Health, Newborn and Child Health, Intrauterine Infection, Diseases of the Genitourinary System, IVF, Prognostic Model.

1 Introduction

Maternal, newborn and child health has been identified as a priority in all the WHO founding documents. There are a lot of studies on this topic. But most of them cover only one particular problem, without covering the area as a whole, which makes them not sufficiently effective when applied in practice. The problem of maternal and child health care must be addressed at the population level. For this purpose, it is necessary to develop and apply in practice management solutions within the city, district and

medical institution. But there is also an individual, personal level. It should provide a doctor with a tool to support the choice of treatment and prevention tactics.

The purpose of the study is to establish a two-stage system for protecting maternal and child health. The first stage of the system involves the use of large databases containing population health data. The goal of the stage is to identify risk groups among the population, estimate the need for medical care for individual medical organizations and their subdivisions, and to forecast the level of public health. The second stage involves the use of personalized predictive models built in the course of individual clinical trials, which are based on clinical and immunological characteristics of the patient. The goal of the stage is the personalized calculation of risks for a particular person, development of measures to reduce the risk, selection of the best algorithm for patient management, depending on the forecast. The research was carried out under the supervision of Professor, Doctor of Medical Sciences, Chechenin G.I.

2 Results

2.1 Population Health Level

Since 1976, employees of the Medical Information and Analytical Center (MIAC) have been maintaining databases on the health status of city residents. Previously, these databases were used only for the preparation of regulated statistical reports. But the development of computer technology has made it possible to conduct regular statistical analysis using mathematical modeling tools. As a result of the previous and new research, a two-level system of maternal and child health protection has been developed.

At the first stage of the system creation, the «indicator problems» was developed. This indicator allows identifying weak points and problematic areas in public health in a dynamic way [1]. This index consists of two parts: the first one reflects the degree of compliance of the considered characteristic with the regulations (based on the Friedman criterion), the second one addresses the presence of a trend (based on the Kendall criterion). The index values are in the range from 0 to 2, where 2 is the extreme severity of the problem. This index was calculated for the public health indicators in Novokuznetsk. As a result, a small but stable annual increase in the stillbirth rate was identified. It was also revealed that Caesarean section surgery was frequently performed without taking into account possible negative consequences for women and children.

A deeper analysis of the problem revealed the lack of an algorithm for preventive risk management for pregnant women and women in labor. Usually a woman was hospitalized and treatment was started only after she had already developed a pathological condition. Thus, it was necessary to develop an algorithm for the formation of risk groups among pregnant women requiring constant increased control. The algorithm is based on a predictive mathematical model of the newborn's viability formation. This model was developed on the basis of information from the databases “Fertility”, “Hospitalization” and “Disease” (the total volume of records was more

than 10 million). Logistic regression with regularization was used to build the model. A large number of complications of pregnancy and childbirth were considered as input variables. A binary variable was considered as an output variable: 0 - a newborn child has all the signs of live birth; 1 – a newborn child has no, one or more signs of live birth. The model was constructed in three phases of pregnancy: the first trimester (10 weeks), third trimester (30 weeks) and beginning of labor activity. The forecast interval in each case was 30 weeks, 10 weeks and 24 hours, respectively.

The management impact based on the forecast leads to significant deviations from the specified value of the output value. Therefore, the direct influence on the object is exerted not on the whole forecast horizon but only on its small initial part, which is considerably smaller than the forecast interval.

For the first half of pregnancy this value is 1 month, for the second half – 2 weeks, from the start of labor activity the parameter is taken equal to 1 hour. The application of this algorithm allows one to estimate the need for specialized obstetric care and to coordinate the work of neonatal intensive care units [2].

An algorithm for planning the frequency of Caesarean section operations was also developed, taking into account the validity of their execution. It is based on the model of the probability of abdominal delivery, depending on the age of the woman, number of births and pregnancies, number of diseases and complications. Logistic regression was used to build the model. The algorithm is designed for the heads of departments of maternity hospitals to distribute human and technical resources of the institution.

In addition to the population databases, MIAC developed an integrated system of social and hygienic monitoring (an interdepartmental system developed at MIAC with the participation of a number of institutions of the health and life support system in Novokuznetsk), whose part was monitoring the health of children and adolescents. The system calculates integral indices, each of them characterizing a different aspect of health. Based on the information from this system an algorithm was developed for the classification of educational institutions in Novokuznetsk. This algorithm is based on clustering all the educational institutions by the values of the integral indices with the subsequent detailed analysis of the institutions of the disadvantaged group. The application of the developed algorithm made it possible to identify problems with respiratory diseases in children, and a clear correlation with the place of residence was observed.

2.2 Personal Health Level

Together with specialists, a number of clinical trials were conducted, and each of them was devoted to a separate problem. In particular, a large percentage of pathological conditions of the newborn was found to be associated with its intrauterine infection. A task was set to develop an algorithm for a personalized antenatal prognosis of intrauterine infection. A risk model of the intrauterine infection was created for the algorithm.

As an output value we used the Apgar score with a split into 2 intervals: from 0 to 6 points – an unfavorable outcome (a child with an intrauterine infection), from 8 to 10 points – a favorable outcome (a child is healthy). The Apgar scale was used due to

the fact that it is commonly employed directly at birth, reflecting the degree of dysfunction of vital organs and systems in the antenatal period.

The input variables were 32 indicators, including the laboratory ones (albumin, lactoferrin and α2-macroglobulin levels in the blood of pregnant women and in the amniotic fluid of women in labor), complicated anamnesis in the mother, associated with immune deficiencies (obesity, fibroids, urolithiasis), and features of childbirth which facilitate the penetration of infection into the fetus (low placenta, discoordination of birth activities). A logistic regression equation was constructed to calculate the probability of the development of infectious pathology of the early neonatal period in the newborn. The accuracy of classification on the test sample was 92.1%. The application of this algorithm makes it possible to detect intrauterine infection of the fetus even at the stage of pregnancy of the mother and to start reasonable antibacterial therapy as early as possible. This algorithm was implemented in the perinatal center and showed its high efficiency. Based on the developed algorithm, a computer program allowing one to calculate the risk of intrauterine infection of the child was written. In the case of high risk, a pregnant woman is hospitalized in a specialized obstetrical hospital, to reduce child morbidity and infant mortality rates.

At the next stage, the developed algorithm was supplemented with a model for predicting the intrauterine infection of the child at premature rupture of the fetal membranes. A direct spreading neural network with a hidden layer (9 neurons) and three outputs (no intrauterine infection, local intrauterine infection, generalized intrauterine infection) was chosen as the modeling method. The weighting factors are presented in Table 1. The accuracy of classification on the test sample was 94.7%.

Table 1. Weighting factors of the neural network indicating the presence of intrauterine infection.

	Input and output layer	Hidden layer neurons									
		*f*1	*f*2	*f*3	*f*4	*f*5	*f*6	*f*7	*f*8	*f*9	b0
Input	Blood α-2-MG	1.14	-1.36	-0.45	1.1	-0.13	1.53	-0.61	-0.68	1.02	-
	Follicular fluid α-2-MG	-0.56	0	0	0	0.44	-0.35	0	-0.01	0	-
	Bacterial vaginosis	0.38	1.17	-1.43	-0.92	-0.45	-1.68	-1.31	1.53	-1.26	-
	Losses of pregnancy	0.46	0.86	-0.69	-0.31	0.39	1.03	-0.55	-0.59	-0.38	-
	Termination of pregnancy	0.22	-0.55	-1.22	1.31	0.08	-0.78	-1.34	-1.03	0.91	-
	Respiratory infection	0.07	0.34	-1.04	-0.32	-0.1	0.54	-1.13	0.78	-0.53	-
	b0	0.15	1.37	1.69	-2.42	-0.24	0.29	2.09	1.3	-1.56	-

Output	No infection	0.18	-0.82	2.44	-1.02	-0.85	2.3	2.5	-0.06	-0.07	-0.27
	Local	1.15	-1.84	-1.89	2.85	0.11	-0.55	-2.36	-2.27	2.11	-0.07
	Generalized	-1.33	2.66	-0.55	-1.83	0.75	-1.75	-0.15	2.33	-2.04	0.34

Further study of neonatal mortality and morbidity reveals that in many cases the cause is beyond the gestational period and concerns the reproductive health of women in general. A number of algorithms were developed for the prognosis of certain diseases of the genitourinary system, which are interrelated with the reproductive potential of a woman. All the developed algorithms are based on the predictive models built using a combination of Random Forest methods and logistic regression. Table 2 shows the parameters of the model risk of adenomyosis in women with fibroids. The simulation results are represented by the coefficient estimates (b), statistical significance of the input variables (p) estimated using the Wald test (W), odds ratio (OR), and its 95% confidence interval. The accuracy of classification on the test sample was 91%.

Table 2. Prognostic model parameters for the development of adenomyosis in women with fibroids.

Factors	**B**	W	p	OR [95%CI]
Concomitant simple endometrial hyperplasia	1.47	8.49	0.004	4.35 [1.62-11.71]
Chronic inflammatory cervical conditions	0.68	4.01	0.045	1.98 [1.05-4.64]
Menometrorrhagia	1.62	4.54	0.033	5.06 [1.13-37.45]
Parity	2.19	9.96	0.002	8.96 [2.3-34.96]
Endometrial pathology in history	2.47	23.50	0.000	11.79 [4.35-31.96]
Varicose veins of the lower extremities	2.08	11.72	0.001	8.03 [2.44-26.46]
Appendectomy in history	1.37	4.30	0.038	3.92 [1.09-23.62]
Lactoferrin over 1.18 mg/mL	1.38	4.12	0.042	3.96 [1.05-14.96]
IL-6 over 2 pg/mL	1.02	3.72	0.054	2.77 [1.06-10.62]
Age 43 years and older	0.82	3.78	0.052	2.27 [1.05-5.78]
Constant	-9.18	26.35	0.001	–

The problem of reproductive potential also includes the infertility of a woman. In some cases, one has to resort to in vitro fertilization. To improve the efficiency of the IVF procedure, an algorithm of the risk of a negative IVF outcome was developed. The algorithm is based on the model of prognosis of a negative outcome of the IVF program in the case of different causes of female infertility. The model was built using the logistic regression method with regularization. Based on the developed model, a forecast scale was formed (Table 3).

Table 3. Parameters of the prognostic model of the negative IVF result.

Factors	Score
Age 31 years and older	3
IVF retry	2
Losses of pregnancy in anamnesis	3
Fibroids	5
Blood albumin concentration below 47.5 g/l (Endometriosis-associated infertility)	9
Blood TNF-α concentration over 3.0 pg/mL (Tubal-peritoneal factor of infertility)	10
Total Protein in follicular fluid below 57 g/l (Tubal-peritoneal factor of infertility)	10
Albumin in follicular fluid below 38 g/l (Polycystic ovary syndrome)	9
IL-8 in follicular fluid below 130 pg/mL (Polycystic ovary syndrome)	7

The threshold sum of points was determined using the index Youden's J statistic (13 scores, J=0.651). If the sum of the points on all the risk factors exceeds (or is equal to) 13, a woman has a high probability of a negative outcome of the IVF program. The accuracy of classification on the test sample was 85%. At high risk it is recommended to manage the patient according to the specialized algorithm of normalization of the immunological background of a woman.

Maternal and child health care involves taking care not only of women and newborns, but also of kindergarten children and adolescents. At the population level, a group of children with increased respiratory illnesses was identified. In such children specialists are faced with the problem of not only treating the disease itself, but also preventing complications. A study was conducted on the risks and effectiveness of immunization of children with lung diseases [3,4]. Based on this study, a personalized vaccination plan is currently being developed which takes into account the risks and possible complications.

The developed system of maternal and child health care has now been implemented in a number of medical institutions of the city. Efforts are being taken to generalize it and extend it to the city level.

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