AN APPLICATION OF THE ANALYTIC NETWORK PROCESS TO RESEARCHING ORAL HEALTH

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ABSTRACT

The article describes applying the Analytic Network Process to model the influence of various factors on oral health status. The network model, based on the knowledge of experts, enables us to find the factors which have a profound effect on the health status of the organism's systems under conditions of interdependence. The outcomes obtained are in conformity with observed data. The procedure described here can be used for research and forecasting the health status of the human organism in general.

Keywords: ANP, caries, dentistry, forecasting, oral health

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1. Introduction

The Analytic Network Process developed by Thomas L. Saaty (Saaty T.L., 2001) can be successfully applied to forecasting a functional state of various forms of human physiological activity using the knowledge accumulated by skilled doctors and physiologists. In this paper we consider the problem of modeling oral health, taking into account a number of external and internal factors.

The forecasting of the onset and development of dental diseases is an urgent problem in modern dentistry as the incidence of dental caries and periodontium pathologies is very high among the human population and their clinical course is progressive. Usually forecasting dental disease is based on clinical presentations of the action of various adverse factors on hard tooth tissues and on the periodontium. As is known, caries and inflammatory diseases of periodontium are caused by both local and general risk factors (Leont'ev V.K., Shestakov V.T. and Voronin V.F., 2003; Rybakov A.I. and Chelidze L.N., 1990).

The well known general risk factors are: content of fluorine in water, the daily diet, stresses, and somatic diseases, which give rise to abnormalities of endocrine regulation, immunity and metabolism.

In this research we take into consideration the following local factors: the presence of carbohydrate food debris, the presence of microorganisms in dental deposits, and abnormal composition and properties of the oral fluid. Besides these factors the resistance of hard tooth tissues (full value of structure, chemical composition, and genetic code) is important to predict the onset of caries.

The Analytic Network Process (ANP) proposes constructing a qualitative model that describes the influence of external factors upon the system under study and the interdependence of the system's elements. Such a model can be built using the knowledge of highly-skilled experts and it represents the linguistic description of basic components, elements and factors, as well as describing the sense and direction of the flow of influence in the system being researched. The influence of different factors upon the system's elements (or the mutual influence of internal elements) can be semantically ambiguous, therefore in the initial research stage one should precisely formulate the main goal in terms of which the basic categories of the task will be determined: criteria, components or clusters, elements, judgments.

2. Constructing the network model

The main goal in this research is to find the factors that make the greatest impact on oral health. The results of scientific research, published scientific works (Rybakov A.I. and Chelidze L.N., 1990; Eriksen H.M. and Bjertness E., 1991; Hollister M.C. and Weintraub J.A., 1993; Leont'ev V.K., Shestakov V.T. and Voronin V.F., 2003; Andreichicova O.N. and Radyshevskaya T.N., 2003), as well as the experience of applied medicine were used to single out 15 major factors influencing oral health. These factors were grouped into the following 7 clusters.

1) Life-support conditions

This term means the external influence of environmental factors upon a human organism, in particular upon oral health. The most important factors among them are represented by the following elements of this cluster:

1.1. Nutrition compound (foodstuff composition; amount of consumed carbohydrates; softness or hardness of food);
1.2. Ecology of life (chemical composition of air and water, including content of fluorine in water; geographic and climatic conditions of existence);
1.3. Social conditions (sanitary conditions depending on social environment and personal income).

2) Oral hygiene

The main external factors determining oral hygiene are:

2.1. Skills of proper tooth brushing;
2.2. Regularity of dental inspections;
2.3. Quality of hygienic means used.

Training patients to brush teeth properly and select hygienic means for oral cavity care decreases the risk of dental diseases.

3) Status of dental health

This cluster characterizes the current state of the oral cavity conditioned by all external and internal influences, as well as by the case history of a patient. There are two main elements here:

3.1. State of teeth;
3.2. State of the periodontium.

The state of teeth (presence of carious cavities, poor-quality tooth stoppings and dental deposits) in many respects determines the state of the periodontium (onset and progress of gingivitis and periodontitis). Besides, the onset of periodontium diseases can be associated with dental anomalies and deformation, errors during prosthetic alignments, and also with dental traumas. Inflammatory diseases of periodontium influence both the general health of the human organism and the state of teeth. A formation of bone recesses at periodontitis finally results in loosening of teeth, while etiological microbe agent promotes caries of hard tooth tissues.

4) General health status

This cluster characterizes the influence of basic parameters of human health on the state of oral cavity. Among these parameters we consider the following elements:

4.1. Hormonal status;
4.2. Age;
4.3. Level of immune reactivity.

We suppose these parameters of general health have an important influence on oral health and no further elaboration is necessary.

5) Type of blood circulation

This is one of the major internal factors influencing dental and periodontium health (Rybakov A.I. and Chelidze L.N., 1990). We shall examine the overall influence of this factor without detailing it with a separate subset of elements and we shall presume that various types of blood circulation (eukinetic, hyperkinetic, hypokinetic) influence the state of other systems in different ways.

6) The type of vegetative regulation

This includes vascular tone, secretions of salivary glands, and also blood supply to teeth and periodontium. This cluster, as well the previous one (a type of blood circulation), is considered at a generalized level, i.e. it is represented by a single element. The influence of the vegetative regulation type (sympathotonic, normotonic and vagotonic) upon the general health of the human organism as a whole and, in particular, upon oral health is beyond question and it is described in a number of scientific works (Rybakov A.I. and Chelidze L.N., 1990; Eriksen H.M. and Bjertness E., 1991; Hollister M.C. and Weintraub J.A., 1993).

7) Salivation system

This cluster is detailed the following set of elements whose influence upon oral health is well known (Borovskiy E.V. and Leont'ev B.K., 1991; Leont'ev V.K., Shestakov V.T. and Voronin V.F., 2003):

7.1. Saliva secretion rate;

7.2. Salivation character (qualitative and quantitative saliva composition).

Such factors as ethnic features, professional insalubrities, harmful habits, etc., were not taken into account in the model because their influence is insignificant in comparison with the factors described above.

After identifying basic elements and clusters it is necessary to ascertain the relations between them. The graph of the clusters' interactions is shown in Figure 1, where the arrows specify influence directions. The arrow from one cluster to another means that all or some elements in the first cluster influence all or some elements in the second cluster. Feedback loops are internal cycles which correspond to mutual influence between elements in the same cluster. In addition to internal cycles, there can be external cycles formed by connections between different clusters. The examples of external cycles in Figure 1 are the closed contours formed by the clusters 3 - 4 - 3, 4 - 6 - 4, 4 - 6 - 5 - 7 - 3 - 4, 4 - 7 - 3 – 4, etc. Let us consider in detail the meaning and direction of the relations between the clusters in Figure 1.

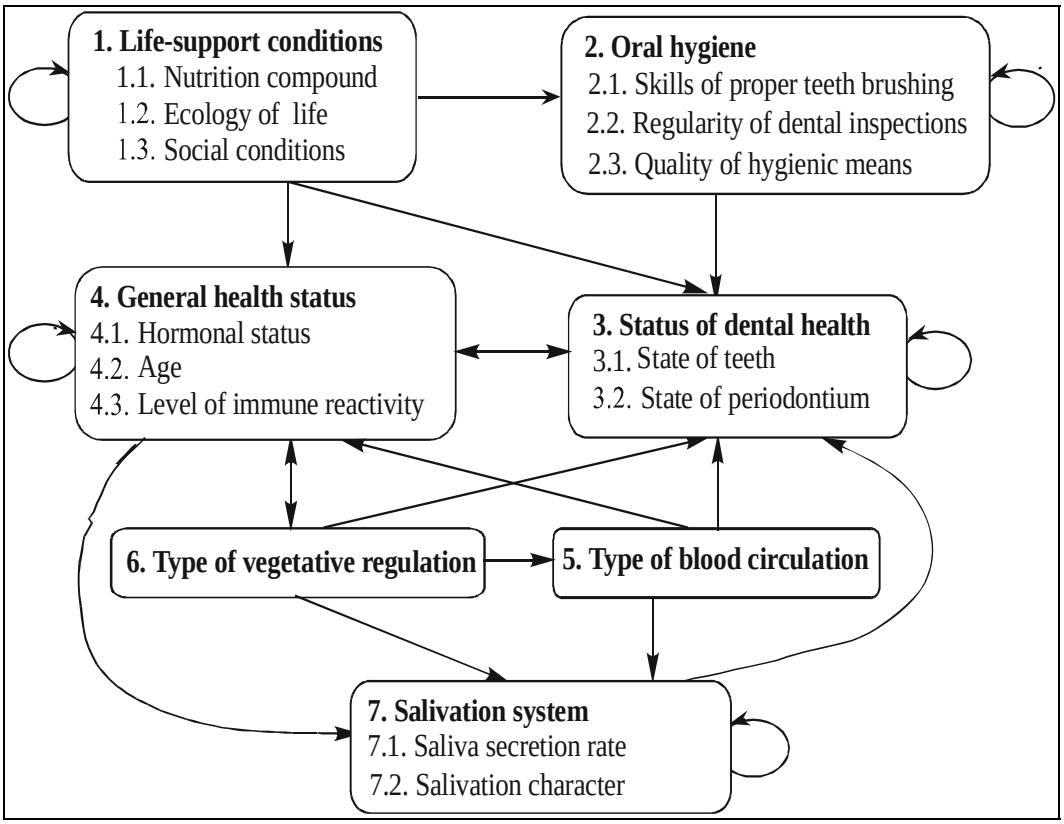

Figure 1 Network model for researching oral health.

The elements in the first cluster *Life-support conditions*, noticeably influence cluster 3, *Status of dental health*, and cluster 4, *General health status*. Besides that, to a lesser degree, they influence each other, and some of them, Social conditions and Ecology of

life, influence the elements of cluster 2, *Oral hygiene*. The most important influences of the first cluster's elements are the following: Social conditions → Nutrition compound, Social conditions → Quality of hygienic means, Nutrition compound → State of teeth, Ecology of life → Level of immune reactivity.

It is obvious that the elements of cluster 2, *Oral hygiene*, influence cluster 3, *Status of dental health*. A feedback loop in the second cluster is our assumption that Regularity of dental inspections influences other elements of this cluster.

In cluster 3, *Status of dental health*, there is the State of teeth element which includes presence of cavities, fillings, and teeth congestion, that in many respects influences the State of periodontium element which, in turn, influences the State of teeth element, i.e., the elements of this cluster influence each other. It is clear that the third and fourth clusters are interdependent, as elements in cluster 3 such as insufficient mastication of food, presence of foci of chronic infections, and inflammations in the oral cavity influence cluster 4, *General health status*.

In turn, the elements of *General Health Status*: Hormonal status, Age and Level of immune reactivity; influence elements in cluster 3 *Status of dental health*. *General health status* besides directly affecting *Status of dental health*, marginally influences *Status of dental health* through cluster 7, *Salivation system*. The type of vegetative regulation depends on the elements in cluster 4, because it can change with age, after sustained diseases and stresses.

The cluster *Type of blood circulation* influences *General health status*, *Status of dental health* (particularly State of periodontium) and *Salivation system*, as the cardiovascular system provides a necessary level of vital activity and is an indicator of the human organism's adaptability.

The cluster *Type of vegetative regulation* influences *Type of blood circulation*, *Salivation system*, *Status of dental health* and *General health status*. The intensity of these influences may be different, but the fact of their existence is beyond question.

The elements of the seventh cluster *Salivation system* mutually influence each other and also *Status of dental health.*

The next step in this research is to find out the relative intensity of influence for all elements examined in the system. Further, the finished model will be used for calculating limiting priorities of the elements. These priorities characterize the overall contribution of every element in the system being formulated.

3. Judging the relative intensity of influence for clusters and elements

In the ANP intensity of influence is estimated by an expert or several experts using the pairwise comparison process and the fundamental scale (Saaty T.L., 2001). The paired comparison technique is the most universal method of measurements, as it can be applied in the absence of any scales and standards, and is particularly useful in determining

measures for intangible attributes. In comparing two objects with respect to a common attribute (criterion, property), the expert estimates how much one object is preferred over another, choosing a suitable representation from the fundamental scale. If there are several parties participating in making judgments they can come to consensus on a judgment or else the geometric mean of their individual judgments can be used. The comparisons for all pairs of homogeneous objects with respect to a criterion are entered in a reciprocal matrix of pairwise comparisons.

There are $(n^2\text{-}n)/2$ judgments required to complete an $n \times n$ pairwise comparison matrix. The right principal eigenvector is calculated for this matrix, which results in a $1 \times n$ vector of relative priorities. This essentially converts the original $(n^2\text{-}n)/2$ judgments to a vector of n numbers from the continuous interval [0, 1] that expresses the relative priority of the elements that were compared. The associated principal eigenvalue also gives a measure of the consistency of the expert's judgments (Saaty T.L., 2001). For our model (see Figure 1), it was necessary to enter judgments in 35 pairwise comparisons matrices for elements and 7 matrices for clusters. The latter were used to calculate the clusters' weight factors. The connections in the network model in Figure 1 are represented by the following matrix:

	Clusters	***1***	***2***	***3***	***4***	***5***	***6***	***7***
	1	***1***	***0***	***0***	***0***	***0***	***0***	***0***
	2	***1***	***1***	***0***	***0***	***0***	***0***	***0***
	3	***1***	***1***	***1***	***1***	***1***	***1***	***1***
B =	***4***	***1***	***0***	***1***	***1***	***1***	***1***	***0***
	5	***0***	***0***	***0***	***0***	***0***	***1***	***0***
	6	***0***	***0***	***0***	***1***	***0***	***0***	***0***
	7	***0***	***0***	***0***	***1***	***1***	***1***	***1***

The unit elements in the matrix *B* signify that the cluster specified at the top (column identifier) influences the cluster specified to the left (row identifier). For each column of this matrix the matrix of pairwise comparisons of corresponding clusters was filled. In filling these cluster comparison matrices, the experts answered a question: "What of two compared clusters influences the given cluster more, and how much more?" or the question "Which of the clusters in a pairwise comparison contributes more to the given cluster, and how much more?" In answering these questions, the experts again used the fundamental scale. For example, influence of the first cluster *Life-support conditions* upon other clusters to which it is connected (the non-zero entries in column 1 of the matrix above) is represented by the following matrix:

	1	***1***	***2***	***3***	***4***	**w**
	1	***1***	***1***	***1/3***	***1/5***	***0.100***
A_1 =	***2***	***1***	***1***	***1/3***	***1/5***	***0.100***
	3	***3***	***3***	***1***	***1/2***	***0.283***
	4	***5***	***5***	***2***	***1***	***0.517***

The elements of the first cluster influence each other and also the elements of the second, third and fourth clusters (see the first column in the matrix *B*). Let us consider the explanation of the expert's results ***w*** for the matrix A_1 containing the clusters pairwise

comparisons obtained by answering the question "What of two clusters does the first cluster, *Life-support conditions*, influence more, and how much more?" We can see that the first cluster's elements have a significant impact on the fourth cluster and somewhat less impact on the third cluster.

The second column of the matrix *B* testifies that the cluster *Oral hygiene* influences itself and the third cluster, thus the pairwise comparisons matrix A_2 is:

A_2 =	*2*	***2***	***3***	**w**
	2	***1***	***1/5***	***0.167***
	3	***5***	***1***	***0.833***

We can see that the elements of *Oral hygiene* (cluster 2) influence elements in *Status of dental health* (cluster 3) more than they influence each other.

Five other pairwise comparison matrices for clusters were similarly filled. The priority vectors thus obtained were used in forming the following matrix of clusters' weight factors:

D =	***1***	***2***	***3***	***4***	***5***	***6***	***7***
1	***0.1***	***0***	***0***	***0***	***0***	***0***	***0***
2	***0.1***	***0.167***	***0***	***0***	***0***	***0***	***0***
3	***0.283***	***0.833***	***0.8***	***0.125***	***0.143***	***0.09***	***0.5***
4	***0.517***	***0***	***0.2***	***0.5***	***0.286***	***0.051***	***0***
5	***0***	***0***	***0***	***0***	***0***	***0.606***	***0***
6	***0***	***0***	***0***	***0.125***	***0***	***0***	***0***
7	***0***	***0***	***0***	***0.25***	***0.571***	***0.253***	***0.5***

The next step is filling out the pairwise comparisons matrices for the elements of the clusters and calculating their priorities. Let us consider this procedure using an example from the first cluster, which contains the following elements: 1.1. - Nutrition compound; 1.2 - Ecology of life; 1.3 - Social conditions. These elements influence each other and also the elements of the second, third and fourth clusters. They do not all influence elements in the other clusters. For example, the Nutrition compound element in the *Life-support conditions* cluster does not influence Ecology of life and Social conditions, however the last two factors influence other elements in the first cluster. We have the following pairwise comparison matrices for the first cluster's elements:

C_{112} =	*1.2*	***1.1***	***1.3***	**W**
	1.1	*1*	***5***	***0.833***
	1.3	***1/5***	*1*	***0.167***

C_{113} =	*1.3*	***1.1***	***1.2***	**w**
	1.1	*1*	***5***	***0.833***
	1.2	***1/5***	*1*	***0.167***

These matrices show that Ecology of life influences Nutrition compound much more strongly than Social conditions, and Social conditions influences Nutrition compound more strongly than Ecology of life.

The second cluster's elements are influenced by all elements of the first cluster except Nutrition compound. Thus, Ecology of life (1.2) influences Regularity of dental inspections (2.2) much more strongly than other elements of the second cluster. The

Social conditions (1.3) factor influences Quality of hygienic means (2.3) to a greater extent than the others and hardly influences Skills of proper tooth brushing (2.1). These influences are represented by the following matrices:

$$C_{212}=\begin{array}{c|ccc|c} 1.2 & 2.1 & 2.2 & 2.3 & \mathbf{w} \\ \hline 2.1 & 1 & 1/7 & 1 & 0.111 \\ 2.2 & 7 & 1 & 7 & 0.778 \\ 2.3 & 1 & 1/7 & 1 & 0.111 \end{array} \qquad C_{213}=\begin{array}{c|ccc|c} 1.3 & 2.1 & 2.2 & 2.3 & \mathbf{w} \\ \hline 2.1 & 1 & 1/4 & 1/8 & 0.077 \\ 2.2 & 4 & 1 & 1/2 & 0.308 \\ 2.3 & 8 & 2 & 1 & 0.615 \end{array}$$

Nutrition compound (1.1) and Ecology of life (1.2) influence the elements of the third cluster (Status of dental health). The following matrices contain estimations of intensity of their relative influence:

$$C_{311}=\begin{array}{c|ccc|c} 1.1 & 3.1 & 3.2 & \mathbf{W} \\ \hline 3.1 & 1 & 5 & 0.833 \\ 3.2 & 1/5 & 1 & 0.167 \end{array} \qquad C_{312}=\begin{array}{c|ccc|c} 1.2 & 3.1 & 3.2 & \mathbf{w} \\ \hline 3.1 & 1 & 3 & 0.75 \\ 3.2 & 1/3 & 1 & 0.25 \end{array}$$

We can see from these matrices that the elements of the first cluster influence State of teeth more strongly than State of periodontium.

All elements in the first cluster influence the elements of the fourth cluster *General health status*. These influences are shown in the following matrices:

$$C_{411}=\begin{array}{c|cccc|c} 1.1 & 4.1 & 4.2 & 4.3 & \mathbf{w} \\ \hline 4.1 & 1 & 5 & 1/2 & 0.319 \\ 4.2 & 1/5 & 1 & 1/9 & 0.066 \\ 4.3 & 2 & 9 & 1 & 0.615 \end{array} \quad C_{412}=\begin{array}{c|cccc|c} 1.2 & 4.1 & 4.2 & 4.3 & \mathbf{W} \\ \hline 4.1 & 1 & 3 & 1/3 & 0.231 \\ 4.2 & 1/3 & 1 & 1/9 & 0.077 \\ 4.3 & 3 & 9 & 1 & 0.692 \end{array} \quad C_{413}=\begin{array}{c|cccc|c} 1.3 & 4.1 & 4.2 & 4.3 & \mathbf{w} \\ \hline 4.1 & 1 & 3 & 1/2 & 0.3 \\ 4.2 & 1/3 & 1 & 1/6 & 0.1 \\ 4.3 & 2 & 6 & 1 & 0.6 \end{array}$$

The matrices above show that Nutrition compound (1.1) exerts the most important influence on Level of immune reactivity (4.3), lesser on Hormonal status (4.1) and nearly does not influence Age (4.2). Ecology of life (1.2) and Social conditions (1.3) influence the elements of the fourth cluster in a similar way.

The pairwise comparison matrices for estimating the influence of the elements from other clusters were similarly formed. The priority vectors computed for these matrices were put in the unweighted supermatrix for this network task, which is shown in Table 1. The experts' judgments in all matrices had a good consistency (the index of inconsistency did not exceed 0.02 while the maximum suggested allowable index of inconsistency is 0.10).

Table 1
Unweighted supermatrix.

	1			**2**			**3**		**4**			**5**	**6**	**7**	
	1.1	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**4.3**	**5**	**6**	**7.1**	**7.2**
1.1	0	0.833	0.833												
1.2	0	0	0.167	0			0		0			0	0	0	
1.3	0	0.167	0												
2.1	0	0.111	0.077	0	0.75	0.25									
2.2	0	0.778	0.308	0.875	0	0.75	0		0			0	0	0	
2.3	0	0.111	0.615	0.125	0.25	0									

3.1	0.833	0.75	0	0.75	0.833	0.833	0	1	0.167	0.5	0.25	0.2	0.25	0.75	0.333
3.2	0.167	0.25	0	0.25	0.167	0.167	1	0	0.833	0.5	0.75	0.8	0.75	0.25	0.667
4.1	0.319	0.231	0.3				0.222	0.236	0	0.667	0.833	0.236	0.25		
4.2	0.066	0.077	0.1	0			0.111	0.082	0.25	0	0.167	0.082	0.069	0	
4.3	0.615	0.692	0.6				0.667	0.682	0.75	0.333	0	0.682	0.681		
5	0			0			0		0			0	1	0	
6	0			0			0		1	1	1	0	0	0	
7.1	0			0			0		0.25	0.75	0.333	0.25	0.75	0	1
7.2									0.75	0.25	0.667	0.75	0.25	1	0

4. Calculation of limiting priorities for the factors

When elements in a complex system influence each other, their priorities constantly change, therefore one can say that the task being considered becomes a dynamic one. We are interested in a long-term forecast of oral health and in the limiting result of the mutual influences of the factors being considered. The ANP enables us to find the steady limit state for a network model with feedback, and also to calculate limiting priorities for all elements and clusters.

If the sums of the elements in every column of a supermatrix are equal to unity, then that the matrix is said to be column stochastic. In order to make the original supermatrix in Table 1 stochastic, which is necessary for its convergence, one must multiply its blocks that correspond to the clusters by the cluster's weight factors shown in the matrix *D*. The result is the weighted supermatrix shown in Table 2. Raising this matrix to powers until it converges results in the solution, which is a square matrix with identical columns whose elements do not change as the powers increase. In some cases the limiting matrix cycles among 2 or more states in which case the states are combined to give a square matrix with identical columns. This matrix contains the limiting priorities of the elements. We can see them in Table 3 and interpret the factors' contributions to the main goal. By main goal in an ANP model we mean the stated objective of the exercise: to find the factors that make the greatest impact on oral health. Unlike in an AHP model where the main goal is the node at the top of the structure, the main goal in an ANP model does not appear as a node in the model. Rather it is the purpose of the model and judgments in the model must be entered with this kept in mind.

5. Results discussion

The outcomes shown in Tables 2 and 3 and in Figures 2 and 3 allow us to conclude the following assertions about the mutual influence of external and internal factors:

- *Life-support conditions* have the most important influence on State of teeth, Level of immune reactivity and Hormonal status.
- *Oral hygiene* strongly influences State of teeth and less State of periodontium.
- The elements of *Status of dental health* noticeably affect each other. To a lesser degree they influence Level of immune reactivity.
- Hormonal status has the most appreciable influence on Level of immune reactivity, Salivation character and State of periodontium.

- Age noticeably influences Hormonal status, Saliva secretion rate, Level of immune reactivity and Vegetative regulation type.
- The Level of immune reactivity appreciably affects Hormonal status and Salivation character.
- *Type of blood circulation* strongly influences Salivation character and has somewhat less influence on Level of immune reactivity and State of periodontium.
- *Type of vegetative regulation* governs *Type of blood circulation*. Besides, it noticeably influence Saliva secretion rate.
- The elements of the *Salivation system* noticeably affect each other. They also have some influence on Status of dental health such that a Saliva secretion rate affects State of teeth, and Salivation character – State of periodontium.

Table 2
Weighted supermatrix

	1			**2**			**3**		**4**			**5**	**6**	**7**	
	1.1	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**4.3**	**5**	**6**	**7.1**	**7.2**
1.1	0	0.083	0.117												
1.2	0	0	0.023		0			0		0		0	0		0
1.3	0	0.017	0												
2.1	0	0.011	0.011	0	0.125	0.042									
2.2	0	0.078	0.043	0.146	0	0.125		0		0		0	0		0
2.3	0	0.011	0.085	0.021	0.042	0									
3.1	0.295	0.212	0	0.625	0.694	0.694	0	0.8	0.021	0.063	0.032	0.029	0.083	0.375	0.167
3.2	0.039	0.071	0	0.208	0.139	0.139	0.8	0	0.104	0.063	0.094	0.115	0.067	0.125	0.333
4.1	0.206	0.119	0.216				0.044	0.047	0	0.333	0.416	0.067	0.013		
4.2	0.043	0.04	0.073		0		0.023	0.017	0.125	0	0.083	0.023	0.004		0
4.3	0.397	0.358	0.432				0.133	0.136	0.375	0.167	0	0.195	0.035		
5		0			0			0		0		0	0.606		0
6		0			0			0	0.125	0.125	0.125	0	0		0
7.1		0			0			0	0.063	0.187	0.083	0.143	0.19	0	0.5
7.2									0.187	0.063	0.167	0.428	0.063	0.5	0

Table 3
Limiting priorities of the elements and clusters

1			**2**			**3**		**4**			**5**	**6**	**7**	
0			0			0.56		0.237			0.018	0.03	0.155	
1.1	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**4.3**	**5**	**6**	**7.1**	**7.2**
0	0	0	0	0	0	0.276	0.284	0.087	0.032	0.118	0.018	0.03	0.071	0.084

The priorities shown in Tables 1 and 2 can be considered as expert estimations of the influence intensity for the set of the examined factors at the present moment. The limiting priorities (see Table 3) can be interpreted as predicting the values of the examined

factors' contributions on the overall goal of the system, oral health. The factors having high limiting priorities affect the system to a greater extent. In other words, data from Table 3 (and the bars in Figure 2) correspond to the concentration of the influence in the elements from all the examined factors. It is easy to note that the elements of Dental health status make the greatest impact on the system goal, and furthermore, the limiting priority of State of periodontium is a little bit more than the priority of State of teeth. The limiting priorities of the clusters are shown in Figure 3, where the striped bars correspond to the integrated contribution of every cluster on the overall system goal. We can see that the contribution of the third cluster (Dental health status) exceeds 50%. The third rank among all the elements (see Figure 2) is Level of immune reactivity, which is an element of the fourth cluster, General health status, which takes the second place among all the clusters (see Figure 3). Another element of this cluster – Hormonal status – has the fourth rank. The element Age is the least significant in the fourth cluster; it can be explained by the negligible influence on it of other factors. The Salivation system has the third rank among clusters, and its elements are in fifth and sixth places (see Figure 2). The Salivation character element is slightly more significant than Saliva secretion rate. In fourth place among the clusters is Type of vegetative regulation followed

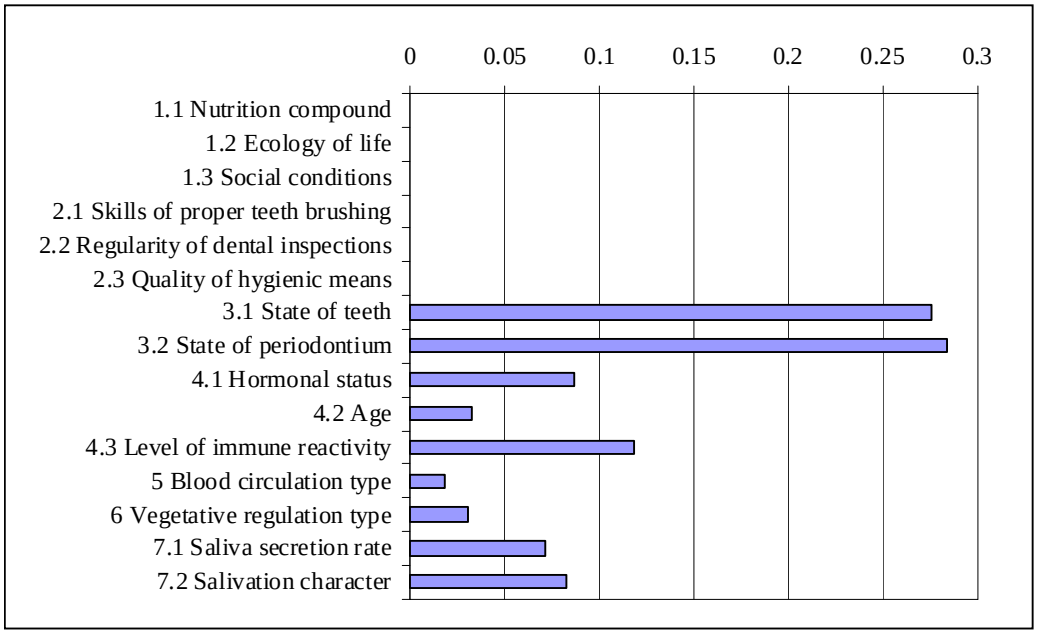

Figure 2 Limiting priorities for the elements of the network model

by Type of blood circulation. The limiting priorities for the elements from the first and the second clusters are equal to zero. This fact can be explained that their elements are not influenced by other elements; therefore there is no accumulation of influence in them. The node corresponding to the first cluster in Figure 1 is a source; and the node, which corresponds to the second cluster, is a flow element with a feedback loop.

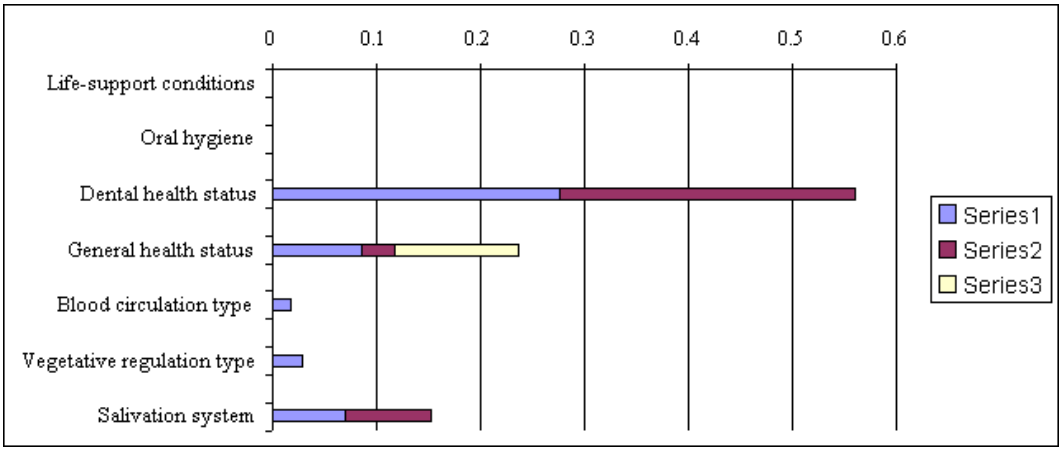

Figure 3 Limiting priorities for the clusters.

The first cluster is a powerful source of influence on the other clusters; only 10% of its influence makes up feedback. The contribution of this cluster's elements to the overall system goal comes through the third and fourth clusters indirectly (see matrix *D* above). The second cluster gets about 10% of the first cluster's influence, and only 16.7% of this value comes back through feedback into it. The contribution of the second cluster's elements on the main goal of oral health has come through the third cluster (*Dental health status*).

In order to find out the elements which have the greatest influence on oral health, we inverted this task by transposing the matrix *B*. To do that it was necessary to fill out a set of new pairwise comparison matrices, asking the experts a question: "Which of two analyzed factors (clusters, elements) influence the given factor (cluster or element) more?" For example, "Which of the elements of *Dental health status* (State of teeth or State of periodontium) influences Level of immune reactivity more?" The supermatrix of the inverted task is shown in Table 4. Its columns show the influences of the factors specified in rows (at the left) upon the element that is the heading of the column. Raising this matrix to high powers enables us to compute the limiting priorities of influence of the examined factors upon all elements of the model. These priorities called the limiting influence priorities are represented in Table 5 and in Figures 4 and 5.

The outcomes of the inverted task reveal the most influential of the factors examined. The obvious leader among them is *Type of vegetative regulation* with a limiting priority of 0.3207, the second is Hormonal status (0.218), and the third is Age (0.1776). The distribution of the clusters' integrated priorities is shown in Figure 5, where we can see that the greatest influence upon *Oral health* is *General health status* (cluster 4) followed by the Type of vegetative regulation and the Type of blood circulation behind it.

The influence of external factors (cluster 1 and 2) is less significant and that coincides with up-to-date concepts in dentistry science (Eriksen H.M. and Bjertness E., 1991; Leont'ev V.K., Shestakov V.T. and Voronin V.F., 2003).

Table 4
The weighted supermatrix of the inverted task

	1			**2**			**3**		**4**			**5**	**6**	**7**	
	1.1	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**4.3**	**5**	**6**	**7.1**	**7.2**
1.1	0	0	0	0	0.071	0.071	0.039	0.039	0.019	0	0.027				
1.2	0.2	0	0	0	0.214	0.071	0.013	0.013	0.056	0	0.054	0	0	0	
1.3	0.8	0	0	0	0.214	0.357	0.006	0.006	0.019	0	0.014				
2.1				0	0.333	0.167	0.176	0.176							
2.2	0			0.75	0	0.333	0.062	0.062	0			0	0	0	
2.3				0.25	0.167	0	0.033	0.033							
3.1	0			0			0	0.272	0.026	0	0.013	0	0	0	
3.2							0.272	0	0.026	0	0.04				
4.1							0.064	0.122	0	0	0.324		0.571	0.097	0.097
4.2	0			0			0.02	0.03	0.324	0	0.108	0	0.286	0.016	0.016
4.3							0.128	0.06	0.108	0	0		0.143	0.048	0.048
5	0			0			0.03	0.03	0.155	0.368	0.155	0	0	0.083	0.083
6	0			0			0.037	0.037	0.266	0.632	0.266	1	0	0.582	0.583
7.1	0			0			0.078	0.029	0			0	0	0	0.174
7.2							0.039	0.087						0.174	0

Table 5 demonstrates that external factors in the first and second clusters are not influenced by internal ones. At the same time, the limiting priority of influence of each factor upon all the other factors is the same. The general physiological factors (clusters 4, 5, 6) have the most important influence upon the general goal of oral health and others element in the model. The influence of *Life-support conditions* (cluster 1) is less than the total influence of the above mentioned factors by approximately 10 times. The second cluster (*Oral hygiene*) and the third cluster (*Dental health status*) have small and close limiting priorities of influence, and the seventh cluster (*Salivation system*) is nearly insignificant.

Table 5
Limiting priorities for the inverted task

	1			**2**			**3**		**4**			**5**	**6**	**7**	
	0.0458			0.0219			0.0224		0.47			0.116	0.3207	0.0033	
	1.1	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**4.2**	**4.3**	**5**	**6**	**7.1**	**7.2**
1.1	0	0	0	0	0	0	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083	0.0083
1.2	0	0	0	0	0	0	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214	0.0214
1.3	0	0	0	0	0	0	0.0161	0.0161	0.0161	0.0161	0.0161	0.0161	0.0161	0.0161	0.0161
2.1	0	0	0	0	0	0	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081
2.2	0	0	0	0	0	0	0.0093	0.0093	0.0093	0.0093	0.0093	0.0093	0.0093	0.0093	0.0093
2.3	0	0	0	0	0	0	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045
3.1	0	0	0	0	0	0	0.0104	0.0104	0.0104	0.0104	0.0104	0.0104	0.0104	0.0104	0.0104
3.2	0	0	0	0	0	0	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
4.1	0	0	0	0	0	0	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218
4.2	0	0	0	0	0	0	0.1776	0.1776	0.1776	0.1776	0.1776	0.1776	0.1776	0.1776	0.1776
4.3	0	0	0	0	0	0	0.0744	0.0744	0.0744	0.0744	0.0744	0.0744	0.0744	0.0744	0.0744
5	0	0	0	0	0	0	0.1159	0.1159	0.1159	0.1159	0.1159	0.1159	0.1159	0.1159	0.1159
6	0	0	0	0	0	0	0.3207	0.3207	0.3207	0.3207	0.3207	0.3207	0.3207	0.3207	0.3207
7.1	0	0	0	0	0	0	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
7.2	0	0	0	0	0	0	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018

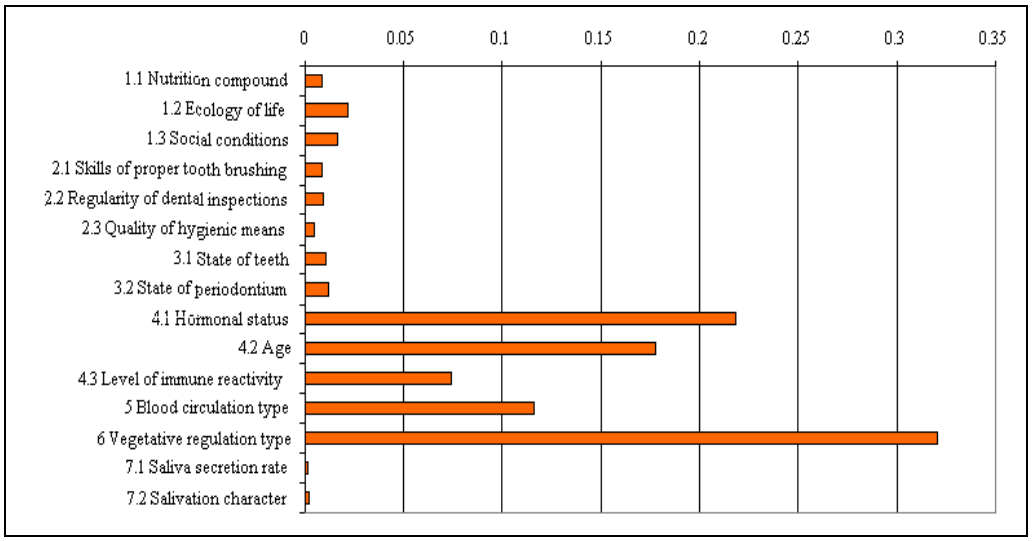

Figure 4 Limiting priorities of influence for the inverted network task.

The results obtained are based on the study of pathological processes in the oral cavity in connection with other organism systems and a human environment. They are well matched with intuitive concepts of the experts, have a reasonable interpretation, and enable us to make a detailed forecast that can be substantiated. The intermediate results are also of interest, as they enable us to analyze the interactions of the elements being

considered. The application of ANP gives an opportunity to estimate the contributions of the external and internal factors that were examined in the oral health system and to predict their influence in view of feedback in the open physiological system.

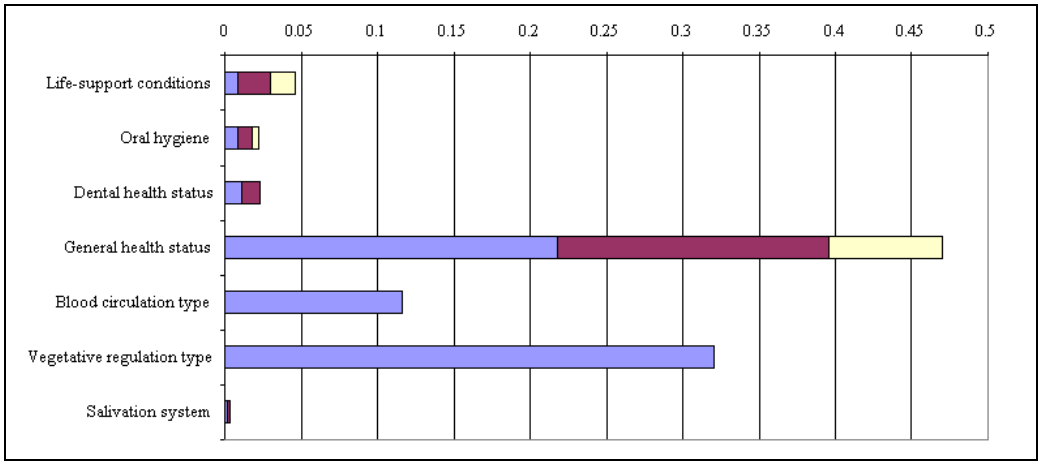

Figure 5 Limiting influence priorities of the clusters from the inverted network model.

The conclusion that the health of oral cavity is governed by the elements of *Dental health status* is well known and validates the expert information used. The new results from this study are the relative priorities describing influence intensity and impact on oral health of such factors as immunity level, hormonal status, vegetative regulation type, blood circulation type, and parameters of salivation system. These results are of a special interest for dentists and physiologists. The influence of the elements of *General health status* is very strong; it is an order greater than the influence of external conditions. Let us note that the small limiting priorities of influence of the external factors should not be interpreted as evidence of their insignificance. The cyclical character of mutual influence between the functional systems in human organism increases the limiting priorities of these factors. For example, the elements of the third cluster (*Dental health status*) influence the elements of the fourth cluster (*General health status*), which in turn influences *Dental health status*, i.e. the influence in the cycle is gradually increased up to some limiting value. Clusters 1 and 2 representing external conditions are not included in the cycles; therefore their impact on *Dental health status* and *General health status* is distributed throughout the system and appears indirectly. This implies that the conditions of life-support and oral hygienic factors become more important when physiological parameters of the human organism are abnormal. In other words, people with immunodeficiency or with abnormalities of blood circulation, hormonal status and vegetative regulation are influenced by ecology, diet and social conditions to a greater degree. Therefore they should care for the oral cavity more attentively and take preventive restorative measures.

The application of ANP to the problem of oral health forecasting has a number of advantages. In particular we might mention the following:

- An opportunity to build a model on the basis of expert information that takes into consideration intangible factors and qualitative parameters;

- Considerable time saving and a wider area of application in comparison with statistical models based on empirical data;
- An opportunity to check out different hypotheses about a structure involving various sets of factors and the intensity of influences within it.

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