ORIGINAL ARTICLE

CONTENTS

The research clinical and instrumental methods of examination of athletes related to the process of intervertebral disk degeneration and stenosis

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ABSTRACT

Aim: To determine the level structure of the graph model of the system of clinical and instrumental indicators of athletes with herniated intervertebral discs complicated by spinal stenosis, and to determine the regression model for these indicators.

Materials and Methods: This observational study involved 64 athletes (14 – rugby players, 16 – handball players, 15 – basketball players, 19 – football players) with intervertebral disc herniation, complicated by stenosis of spinal canal. Research methods: visual method to evaluate the likelihood of a data set's normal distribution; correlation and regression analysis; method for determining the ordinal function of a graph through the application of an adjacency matrix, specifically utilizing Demucron's algorithm. This process is accompanied using a topological sorting of the graph.

Results: The results showed the lack of correlation between age and VAS, muscle strength and VAS, as well as VAS and the channel space; little feedback between age and the channel space; weak positive relationship between size of herniated intervertebral disc had a with the length of the illness. The data showed, strong feedback was observed for hernia size and the channel space, hernia size and muscle strength, the channel space, and length of the illness.

Conclusions: The evaluation on the complexity and depth of the interconnections between clinical and instrumental metrics in athletes was conducted. The hierarchical organization within the graphical representation was ascertained. A predictive regression model delineating the correlations between clinical and instrumental variables in patients suffering from herniated intervertebral discs, with the complication of spinal canal stenosis was established.

KEY WORDS: athletes, stenosis of spinal canal, regression model, demucron's algorithm

Wiad Lek. 2024;77(9):1693-1703. doi: 10.36740/WLek/191321 DOI

INTRODUCTION

The intensive training and competitive activities in team sports significantly elevate the risk of accelerated degenerative disc disease in athletes, underscoring the importance of specialized training and preventive measures [1-3]. For example, in handball, basketball, rugby, football where agility, speed, strength, and frequent bending and twisting are essential, athletes face unique spinal challenges, making tailored training and injury prevention strategies crucial for their long-term health and performance. Given the high biomechanical stress on the lumbar spine in team sports focused training programs that balance strength and flexibility are vital to minimize the risk of spinal injuries. The specific demands of team sports on athletes' spines highlight the need for dedicated research and development of targeted training routines to enhance performance while reducing injury risks [4-6]. In team sports, where quick movements and intense physical exertion are common, developing training protocols that address the high incidence of spinal issues is critical for athlete longevity and success.

Low back pain indicates the presence of a serious health problem in only 1-2% of cases, and indicates the corresponding symptoms, a kind of "red flags". Example of such symptoms is impaired sensitivity of the extremities, muscle weakness, dysfunction of the pelvic organs, the appearance of pain at night, fever and unmotivated weight loss, cancer and ets. [7, 8]. Various etiological factors can be manifested a similar clinical picture.

The problem of vertebrogenic pathology in sport was considered quite widely. At the same time, a number of specific methodological issues remain poorly developed. Athletes spend a significant part of their lives in training and competitive activities, developing agility, speed, strength, power, bending and twisting in their sport. The high intensity and repetition of these exercises predisposes athletes to accelerated degenerative disc disease (DDD), which is theoretically higher than among the general population [9, 10]. This may be due to the fact the lumbar spine is the recipient of the heaviest biomechanical stress.

An important role in the intervertebral connection and the movement of the spine in general is played by the intervertebral disc (IVD), the degeneration of which is a common and chronic process. And as a result, it leads to serious symptoms of the spine, which causes corresponding pain in the lower back of athletes. It is generally known that low back pain and other neurological symptoms caused by intervertebral disc herniation can develop as a secondary condition, and is usually accompanied by a narrowing of the intervertebral disc, the formation of osteophytes and, as a result, stenosis of the spinal canal. This may be of great importance in the choice of tactics and operative treatment of mid-spinal discs, accelerated by stenosis of the spinal canal, which can lead to the "Failed Back Surgery Syndrome" (FBSS) [11]. Surgery does not stop the degenerative process and symptoms may reappear within several years. So, a number of scientists in Japan conducted a cross-sectional, Internet-based survey to assess the prevalence and characteristics of FBSS, which showed – 20.6% of patients with FBSS at 94% – low back pain, 71.1% – dull ache and 69.8% – cold sensations [12], in the UK achieved a response rate of 52% [13]. In general, a recent published study suggested avoiding the use of the term FBSS with regard to its partially stigmatizing connotation and its inherent hindering to provide individualized medicine, due to the fact that he rather unspecific and a variety of conditions may underlie this label [14].

The large number of cases are missed with information from the public domain and introduces bias into the internet-based study. No studies of lumbar disc herniation utilized team medical record data [15]. Therefore, an important step is to create a network (an international panel of spine surgeons, neurosurgeons, and pain specialists with a particular interest in FBSS established the chronic back and leg pain (CBLP) network with the aim of addressing the challenges and barriers in the clinical management of FBSS patients by building a common transdisciplinary vision) [16].

Clinical manifestations of spinal canal stenosis (SCS) sometimes lead to disability (this is likely related to the excessive mechanical stress and physical injury sustained by athletes), so solving the problem of timely diagnosis and, accordingly, proper treatment is important.

AIM

Aim of the study to determine the level structure of the graph model of the system of clinical and instrumental indicators of athletes with herniated intervertebral discs complicated by spinal stenosis, and to determine the regression model for these indicators.

MATERIALS AND METHODS

PARTICIPANTS

To achieve this goal on the basis of the neurosurgical department of "Zaporizhzhia Regional Clinical Hospital" (Zaporizhzhia, Ukraine) and Department of Orthopedics and Traumatology, "House of Medicine Odrex", (Odesavw , Ukraine) during the period from 2017 to 2022 y.o. we performed a prospective, cohort, comparative study involving 64 athletes (14 – rugby players, 16 – handball players, 15 – basketball players, 19 – football players) with an established diagnosis (according to a comprehensive clinical and neuroimaging study within 24 hours of the onset of the disease): intervertebral disc herniation, complicated by stenosis of spinal canal. Clinical neurological manifestations and MRI criteria of the spinal canal were analyzed of all patients by age, size and location of intervertebral disc herniation, level and type of spinal canal stenosis, disease duration, in accordance with muscle strength scale of the British Research Committee and Visual Analogue Scale (VAS).

All patients volunteered to participate in the research. Prior to the testing, the procedures were explained to all of them, including possible risks involvement, and, after the explanation, an informed consent form was signed. The participants entered the study after providing their written informed consent. The study has been approved by the Institutional Ethics Committee, complied with all relevant national regulations and institutional policies, followed the tenets of the declaration of Helsinki, and has been approved by the authors' ethical review committee of Zaporizhzhia National University (number 2022/21–01). Exclusion criteria were a history of injury or disease that would prevent participants from safely performing the study protocol.

A systematic science review was applied in accordance with the Preferred Reporting Items for system-

Table 1. Average values of clinical and instrumental indicators

Indicators	Intervertebral disc herniation size, mm	Spinal canal area, mm^2	Duration of the disease, months	Muscle strength, score	VAS
Arithmetic mean	7,57	58,77	9,84	3,75	7,53
Mo	7,5	66,00	10	4	7
Me	8	65,00	10	5	8
Standard deviation	1,91	21,01	12,35	1,30	1,47
Arithmetic mean error	0,21	2,35	1,38	0,15	0,16
As (Asкр=1.25)	-0,04	-0,48	1,39	-0,70	-0,01
Ex ($Ex_{кр}$=3.5)	-0,42	-0,63	0,39	-0,54	-0,79

atic reviews and meta-analyses. Electronic databases: Scopus, Web of Science, PubMed – were searched for relevant publications. The publications included met the following criteria and principles: included handball players; contained relevant data concerning in handball; were written in English, Poland, Ukraine.

RESEARCH METHODS

- a graphical technique for assessing whether or not a data set is approximately normally distributed (Normal Probability Plot);
- methods for determination of the correspondence of the distribution to the normal law according to the indicators of the distribution form;
- method of average values;
- correlation analysis;
- regression analysis.

Also, method for finding the ordinal function of a graph, based on the use of an adjacency matrix (Demucron's algorithm) [17] is used in the study, and topological sorting of the graph is carried out.

To check the correspondence of the series to the normal distribution law, we used a graphical method for determining the correspondence of the sample values to the normal distribution (Normal Probability Plot), indicators of the central tendency and indicators of the distribution form.

A symmetrical distribution is called normal, in which the maximum values of the studied feature are concentrated around the average value. The curve of normal distribution is symmetric under the y-axis and asymptotically approaches to the abscissa. As a rule, the empirical (actual) distribution differs to some extent from the normal one [17]. The central tendency is the property of the values of the studied feature to be grouped around the center of frequency distribution, the statistical characteristic of which is the average value.

The condition for normal distribution (as symmetric) is the following ratio of the indicators of the distribution center:

- equality of the average (sample mean) value, mode (the most common value of a feature in units of a given population) and median (the value of a feature falling in the middle of a ranked (ordered) population);

- in symmetric distribution series, the value of the mode and the median coincide with the average value (Xav = Me = Mo) [Gorkavy & Yarova, 2004], and in moderately asymmetric series they are related in this way:

3(Xav-Me) ≈ Xav-Mo

To assess the deviation of the empirical distribution from the normal, we have used the following indicators of the form of distribution:

⇒ *moment coefficient of asymmetry (As)*, as the most accurate and widespread indicator of asymmetry (a negative sign indicates the presence of left-sided asymmetry, a positive sign indicates right-sided asymmetry):

$As = M_3/\sigma^3$,

where M_3 – is the central moment of the third order; σ – is the standard deviation, and M_3 is calculated by the formula:

$$M_3 = \frac{\Sigma (Xi - Xcp)^3 fi}{\Sigma fi}$$

The assessment of the significance of the asymmetry indicator is given using the mean square error of the asymmetry coefficient:

$$s_{As} = \sqrt{\frac{6(n-2)}{(n+1)(n+3)}}$$

If the ratio $|As|/S_{As} < 3$, is satisfied, then the asymmetry is insignificant, its presence is explained by the influence of various random circumstances. If the ratio |As|/SAs > 3 takes place, then the asymmetry is significant and the distribution of the feature in the general population is not symmetrical [18].

⇒ *an indicator of kurtosis (peakedness),* which is the fall of the top of the empirical distribution up or down from the top of the normal distribution curve. Most often, kurtosis is estimated using the indicator:

$Ex = M_4/\sigma^4 - 3$,

where M_4 – is the central moment of the fourth order,

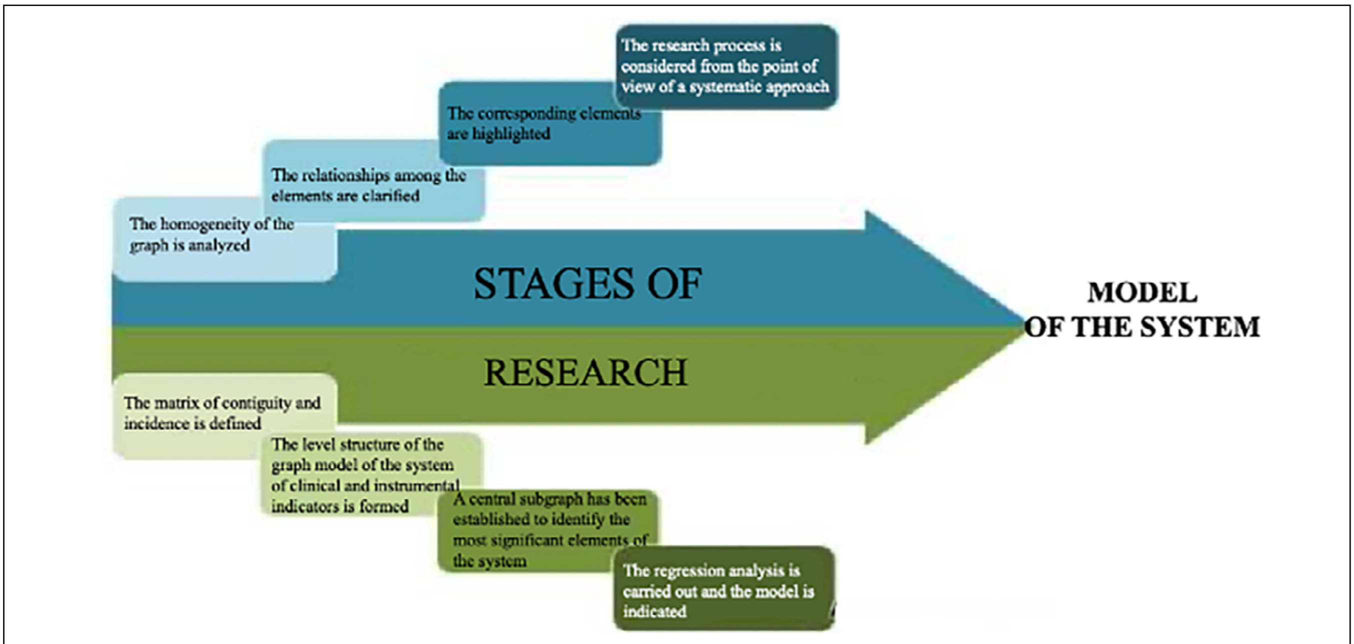

Fig. 1. Stages of research.

σ – is the standard deviation.

For distributions that are more peaked (elongated) than normal, the kurtosis index is positive (Ex > 0), for more flat-topped (oblate) – negative (Ex < 0), because for normal distribution:

$M_4/\sigma^4 = 3$,

to assess the significance of the kurtosis, the Ex/S_{Ex} statistics is calculated, where S_{Ex} is the mean square error of the kurtosis coefficient:

$$s_{Ex} = \sqrt{\frac{24n(n-2)(n-3)}{(n+1)^2(n+3)(n+5)}}$$

If the ratio Ex/sEx > 3, then the deviation from the normal distribution is considered significant.

Compliance with the normal distribution law (according to the indicators of the distribution form) was determined by the method: instantaneous asymmetry factor (As) (estimation of the significance of the asymmetry index was determined using the root mean square error of the asymmetry coefficient) and the kurtosis index Ex (the significance of the kurtosis was determined using the root mean square error of the kurtosis coefficient). We have used regression analysis to model the relationship between the selected variables as well as the predicted values based on the model. Regression analysis uses the chosen estimation method, the dependent variable, and one or more explanatory variables to create an equation that estimates the values of the dependent variable.

STAGES OF RESEARCH

Stage one. The research process is considered from the point of view of a systematic approach.

Stage two. The corresponding elements are highlighted.

Stage three. The relationships among the elements are clarified (how the change in one element affects the state and parameters of the other elements).

Stage four. The homogeneity of the graph is analyzed.

Stage five. The matrix of contiguity and incidence is defined. The use of its adjacency matrix and incidence matrix instead of a graph makes it possible to involve the entire "arsenal" of matrix theory in the study of the graph.

Stage six. The level structure of the graph model of the system of clinical and instrumental indicators is formed.

Stage seven. A central subgraph has been established to identify the most significant elements of the system.

Stage eight. The regression analysis is carried out and the model is indicated.

RESULTS

Analysis of the experimental data results has revealed their compliance with the normal distribution law for each of the clinical and instrumental parameters (Table 1).

Pearson's linear correlation coefficients and regression equations were calculated for all the above data.

The value of a special indicator, the correlation coefficient (r_{xy}), was used to estimate the relationship density in the correlation analysis.

$$r_{xy} = \frac{\sum_{i=1}^{n}(Xi - \overline{X})(yi - \overline{y})}{\sqrt{\sum_{i=1}^{n}(Xi - \overline{X})^2 \sum_{i=1}^{n}(yi - \overline{y})^2}}$$

where Xi and Уi – variants of 2 samples; $\overline{x}$ i $\overline{\acute{o}}$ – the

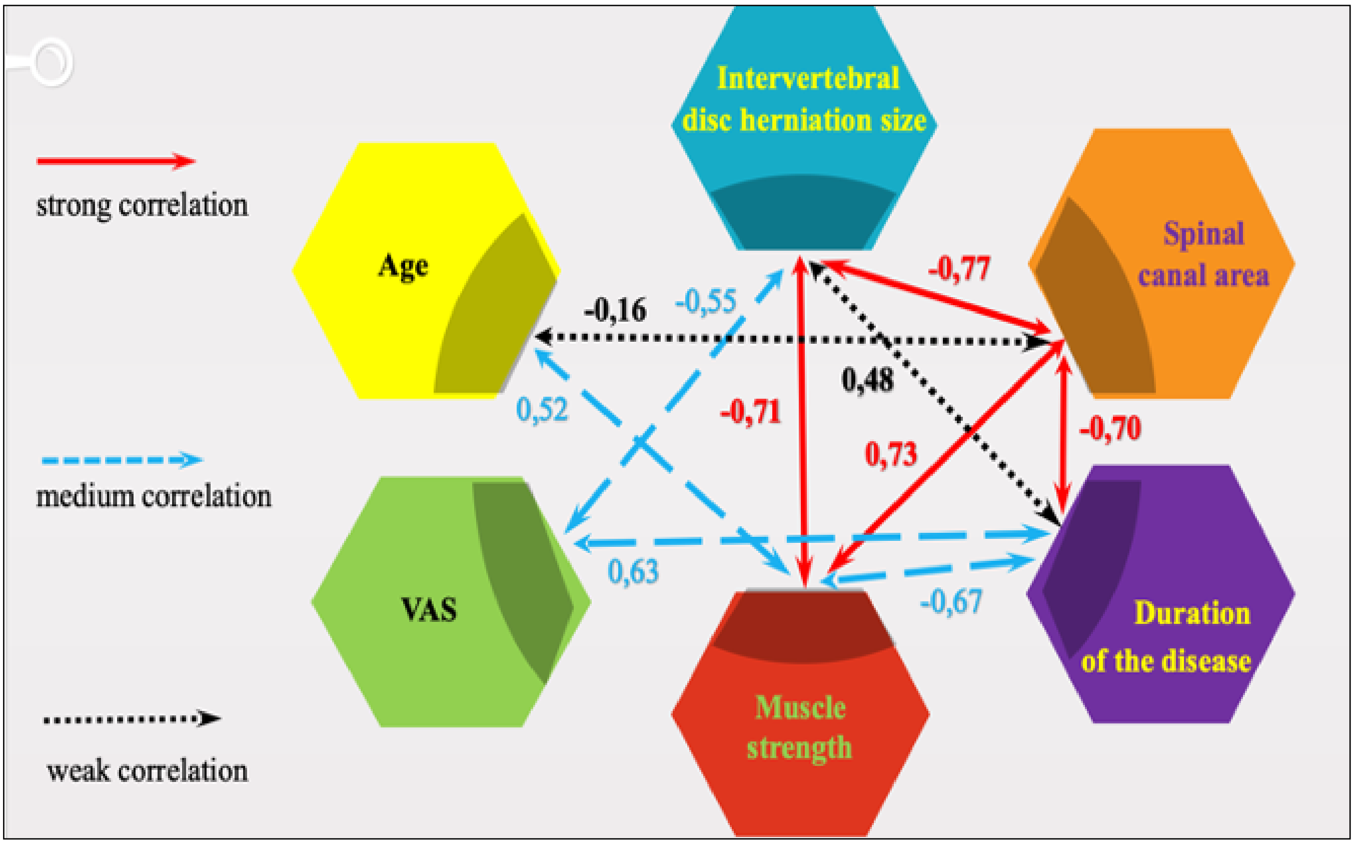

Fig. 2. Diagram of the relationship between clinical and instrumental parameters of patients with intervertebral disc herniation complicated by spinal canal stenosis.

arithmetic mean of the indicators Xi and Yi.

The absolute value of the correlation coefficient is in the range from 0 to 1 – direct positive correlation statistical dependence and from (-1) to 0 – inverse negative correlation statistical dependence:

$$-1 \leq rxy \leq 1$$

We explain the value of this factor in this way:

a) rxy = 1 the relationship between the signs is very dense (functional relationship);

b) rxy = 0 there is no connection between the signs of Xi and Yi;

c) the closer the value of rxy to zero, the weaker the relationship, the closer the value of rxy to one – the denser.

It is assumed that rxy = 0,2....0,49 – weak connection; rxy = 0,5....0,69 – average connection; rxy = 0,7....0,99 – close (strong) connection.

According to the obtained data, we can state the lack of correlation between such indicators as: age and VAS, muscle strength and VAS, as well as VAS and the Spinal canal area (Fig. 1). It should be noted that there is little feedback between age and the Spinal canal area. Instead, indicators of intervertebral disc herniation size had a weak positive relationship with the duration of the disease. The average positive relationship was observed between age and muscle strength, between the duration of the disease and VAS. However, average feedback was observed between intervertebral disc herniation size and VAS, duration of the disease, and muscle strength.

Our observations and special studies in this context have shown that in the end the close connection is obtained by the spinal canal area and the strength of the muscles. However, strong feedback was observed for intervertebral disc herniation size and the Spinal canal area, intervertebral disc herniation size and muscle strength, the Spinal canal area, and duration of the disease.

We also have analyzed the existing model of the relationship between clinical and instrumental indicators of patients with intervertebral disc herniation complicated by spinal canal stenosis by analyzing the graph G = (V, E), which consists of many vertices (v_1, v_2, …v_n), to which belong the indicators, and the set of edges E = (e_1, e_2, …e_n) – the presence of a relationship among them. So, v_1 – spinal canal area; v_2 – duration of the disease; v_3 – muscle strength; v_4 – VAS; v_5 – age of patients; v_6 – intervertebral disc herniation size.

To determine the homogeneity of the graph, the cardinality of the neighborhood of each of the vertices of the graph is recognized, which was calculated by establishing the set of vertices adjacent to the given adj(vi). The number of such vertices is called the degree

A=

	v_1	v_2	v_3	v_4	v_5	v_6	$dev(v_i)$
v_1	0	1	1	0	0	1	3
v_2	1	0	1	1	0	1	4
v_3	1	1	0	0	1	1	4
v_4	0	1	0	0	0	1	2
v_5	0	0	1	0	0	0	1
v_6	1	1	1	1	0	0	4

Fig. 3. Adjacency matrix of graph G.

of the vertex deg(vi), from which we can conclude that:

adj(v_1) ={v2, v3, v6}; deg(v_1)=3

adj(v_2) ={v1, v3, v4, v6}; deg(v_2)=4

adj(v_3) ={v1, v2, v5, v6}; deg(v_3)=4

adj(v_4) ={v2, v6}; deg(v_4)=2

adj(v_5) ={v3}; deg(v_5)=1

adj(v_6) ={v1, v3, v4, v6}; deg(v_6)=4

The graph is heterogeneous, since the degrees of the vertices are not the same.

For further analysis of the graph, the adjacency matrix and the incidence matrix of graph G were identified. Thus, we have considered the adjacency matrix as a symmetric square matrix A=[aij] of order n, in which the element aij=1 if the graph contains an edge {vi vj} (that is, the vertices are adjacent), and aij=0 if there is no such edge (Fig. 2).

The incidence matrix of the graph G is revealed as a square matrix B=[bij] of order n, in which the element bij=1, if the vertex vi is incident to the edge ei and bij=0 in the opposite case (Fig. 3).

To determine the central and peripheral vertices of the graph, its eccentricity (ecc(v_i)) is determined, showing the greatest distance between this and any other vertex of the graph – the distance to the farthest vertex of the graph from v_i:

ecc(v_1) = ecc(v_2) = ecc(v_3)=ecc(v_6)=2

ecc(v_4)=ecc(v_5)=3

The radius r of the graph – the minimum eccentricity among all the vertices of the graph – was calculated by the formula: r(G)=mix ecc(v_i) = 2

The diameter d of the graph – is the maximum eccentricity among all the vertices of the graph, that is, d – is the greatest distance between all pairs of the vertices of the graph.

d(G)=max ecc(v_i)=3

To find the diameter of the graph, first we have found the shortest paths among all pairs of vertices. The greatest length of the shortest path – is the diameter of the graph. The central vertex of the graph of radius r – is the vertex whose eccentricity is equal to r, that is, the vertex at which the radius is reached. Thus, we have defined the set of all central vertices of the graph: {v_1 (spinal canal area), v_2 (duration of the disease), v_3 (muscle strength), v_6 (intervertebral disc herniation size)}.

The peripheral vertex of the graph with diameter d – is the vertex whose eccentricity is d, therefore, the peripheral vertices were {v_4 (age of patients), v_5 (VAS)}.

Consequently, the level structure of the graph model

B=

	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	e_9	B_i
v_1	1	0	1	0	0	0	0	0	1	3
v_2	1	1	0	0	1	0	0	1	0	4
v_3	0	1	1	1	0	0	1	0	0	4
v_4	0	0	0	0	0	1	0	1	0	2
v_5	0	0	0	0	0	0	1	0	0	1
v_6	0	0	0	1	1	1	0	0	1	4

Fig. 4. Incidence matrix of graph G.

of the system of clinical and instrumental indicators of athletes with herniated intervertebral discs complicated by stenosis of the spinal canal has been established (Fig. 4, Fig. 5). So, the center of the graph is the subgraph G1 – a cycle (a chain in which the first and last vertices coincide). The subgraph G1 is connected – all vertices are reachable from each, and is a maximally connected subgraph of the graph G. In order to carry out further research of the obtained data, a regression analysis has been made to calculate the assumed relationship between the dependent variable and one or more independent variables.

The following regression equation is made for muscle strength:

$$S_{muscle} = 3{,}12 + 0{,}04 \times A_{spinal\ canal} - 0{,}03 \times D_{disease}\ (p<0{,}001).$$

DISCUSSION

According to statistics, narrowing of the spinal canal is most common among senior and elderly people, whose structural elements of the spine have undergone age-related changes [18], such as fully fused epiphyses and degenerative wear on her vertebrae. However, other scientists, on the other hand, argue that this problem is more common among athletes than in the general population, due to constant pressure on the spine and simultaneous microtrauma that is unable to heal [19]. Our results are consistent with previous studies that showed a higher incidence of these degenerative changes in the lumbar spine in athletes [20]. Thus, the issues of lumbar spine anomalies were considered in both adolescents [21] and adult athletes [22, 23]: in golf [24], in football [25], in baseball [26] and other kinds of sport. A 17-year study of injuries by the National Basketball Association (NBA) has found that 10.2% of all injuries were to the lumbar spine, where disc degeneration and lumbar contusion accounted for 7.9% and 0.9% of the total [27], which is comparable to our study. Researchers also found out that 95% of hockey players complained on low back pain in the last year of the game [28], and 75% of gymnasts had disc degeneration [29]. Among baseball players, 35.1% and 22.8% of [30] athletes showed signs of L5/S1 or L4/L5 disc degeneration. Researchers stresses the lifetime prevalence low back pain is as high as 77.5% in tennis players [31]. This is likely related to the excessive mechanical stress and physical injury sustained by athletes. Scientists insist on microdiscectomy of the lumbar, confirming the data on the return of 75% to 100% of elite athletes to training for 6 months [32]. Of course, given the popularity of sports and lumbar pathology that players face during and after their careers, we need future researches in oder to understand better the

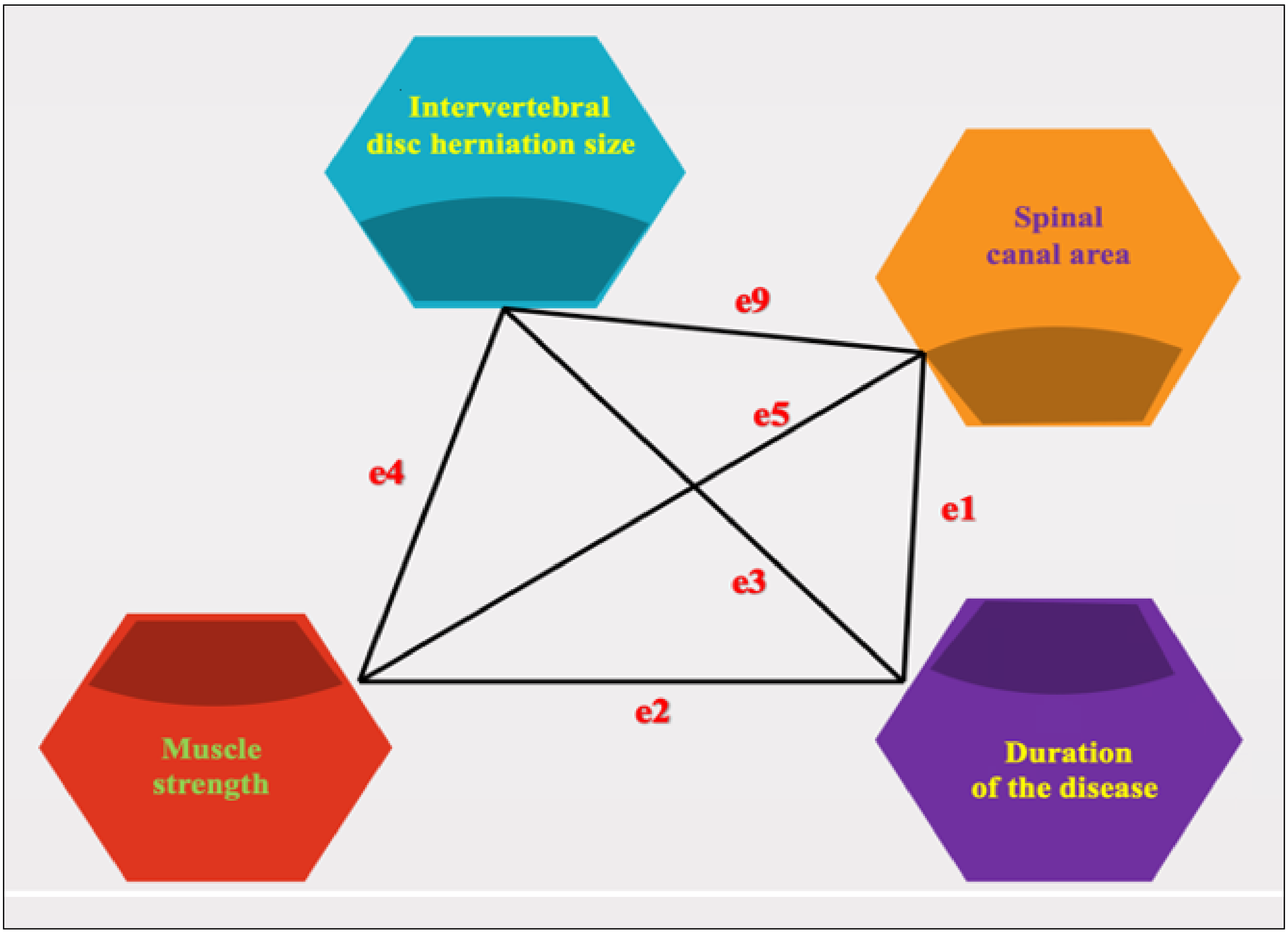

Fig. 5. Subgraph G1 of the graph model of the system of clinical and instrumental indicators of athletes with herniated intervertebral discs complicated by spinal canal stenosis.

mechanisms of injury.

Scientific publications on spontaneous resorption of intervertebral disc herniations (about 70%) havfe appeared regularly since 1984, and are confirmed by CT and MRI studies. In most cases, the resorption period lasts from 3 to 12 months. As a rule, the symptoms disappear much earlier [33]. Furthermore, our study has shown that this is due to the body's natural reactions, such as, an inflammatory reaction to fragments of the pulpal nucleus of the disc, from which the hernia consists of (phagocytosis, enzymes), immunological reactions or due to dehydration (dewatering) of the dropdown fragment (80% of the inner nucleus consists of water).

Progression of stenosis with intervertebral disc herniation at the cervical and thoracic levels can lead to irreversible damage, but at the lumbar level, due to anatomical features, due to the absence of the spinal cord below L1, can lead to severe spondylosis, and as a consequence to severe neurological disorders. Thus, the correct assessment of changes on MRI with the conducted clinical correlation is a key component which should be considered in the course of a choice of surgical intervention at pathology of lumbar spine [34]. There are cases when MRI picture of stenosis of the spinal canal, 20% is asymptomatic or accompanied by minimal low back pain without the development of intermittent claudication [35]. According to MRI studies, disc herniation is often found without symptoms, i.e. without back and leg pain [36]. If you still have back pain, then an MRI hernia may not be the source of the pain.

The data obtained make it possible to optimize the indications for differential surgery or treatment tactics. May also be useful for identifying patients with risk of stress fracture. Earlier recognition of these conditions, a personalized approach, detailing the preoperative neuroimaging situation, features of the clinical picture of the disease, or rational differentiated use of various techniques based on the level structure of the graph model of the system of clinical and instrumental indicators can help not only in the development of methods for preventing early degenerative changes in the spine, but will also improve the efficiency of rehabilitation means.

CONCLUSIONS

1. The assessment of the density of the relationship between clinical and instrumental parameters of athletes with herniated intervertebral discs complicated by spinal stenosis was carried out.
2. The level structure of the graph model of the system of clinical and instrumental indicators of patients with herniated intervertebral discs complicated by spinal stenosis was determined.
3. The most informative clinical and instrumental indicators of athletes with herniated intervertebral discs complicated by spinal canal stenosis were revealed.
4. A regression model of the relationship between clinical and instrumental parameters of patients with herniated intervertebral discs complicated by spinal canal stenosis was determined.

Prospects for further research will be aimed at analyzing of the frequency of occurrence and location of herniated intervertebral discs complicated by spinal stenosis, the age of patients, specialization in sports, and gender characteristics.

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This study was supported by Department of Neurosurgery, Zaporizhzhia Regional Clinical Hospital (Zaporizhzhia, Ukraine) and Department of Orthopedics and Traumatology, "House of Medicine Odrex", (Odesa, Ukraine). The authors wish to acknowledge the involvement sportsmen involved in this study.

CONFLICT OF INTEREST

The Authors declare no conflict of interest

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RECEIVED: 24.12.2023
ACCEPTED: 17.07.2024